

6 October 2002  
Application No.: 09/761,514  
Docket: 1064.us

1317 24. (amended) A process as claimed in claim 23, wherein the step of aligning the optical components in response to the optical signal comprises deforming the optical components.

25. (amended) A process as claimed in claim 23, wherein the step of aligning the optical components in response to the optical signal comprises deforming mounting structures of the optical components.

26. (amended) A process as claimed in claim 23, wherein the step of aligning the optical components in response to the optical signal comprises aligning the optical components to maximize a level of the optical signal that is transmitted through the optical train.

27. (amended) A process as claimed in claim 23, wherein the step of aligning the optical components in response to the optical signal comprises aligning the optical components to maximize a side mode suppression ratio of a tunable optical filter in the optical train.

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**Remarks:**

Claims 1-28 are pending in this application. Claims 1, 7, 21, and 23-27 have been amended in various particulars.

Turning first to formal matters, the drawings were objected to. A number of instances of a lack of agreement between the drawings and the specification were identified in paragraphs 1-3 of the pending Office Action.

Relative to paragraph 1, the issue concerning reference character 140 has been resolved by amendment to the specification. Specifically, the specification now refers to bench jig with reference character "144". This is in agreement with the formal drawings as filed.

Reference character "215" in Figs. 1 and 6 refers to the same aspect of the inventive process. Specifically, it refers to the process of optical component

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characterization through metrology. As a result, Applicants respectfully believe that no drawing correction is required.

Relative to paragraph 2, reference character 144 is now addressed in the specification. Reference numeral "150" on page 12, line 14 was incorrect. Reference numeral "250" should have been used, referring to the alignment based on the metrology data.

Concerning paragraph 3, reference character "215", as discussed previously, refers to the optical component characterization. It is mentioned in the description at, for example, page 8.

Reference character "54" has been added to the specification at page 11, to refer to the optical elements.

In addition to addressing the foregoing issues, the specification has been generally proofread for grammatical errors. Applicants thank Examiner for the obviously careful reading of the specification and the helpful suggestions concerning its improvement.

The grammatical error in the abstract has been corrected. Concerning the location of the "Summary of the Invention" sub-heading, Applicants believe that its location is correct. Issues generally discussed on page 3 concern the recognition of the problem with the conventional techniques. As such, it is part of the basis or motivation for the present invention.

Claim 7 and 24-28 were objected to for informalities. Specific changes were suggested to those claims. Those changes have been carried forward in the foregoing amendments.

Claims 1-28 were rejected under 35 U.S.C. § 112, second paragraph, as being indefinite. Again, specific changes were suggested to claims 1, 21, 23, and 7. The claims have been amended to remove the basis for this objection.

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Specifically, claim 1, as amended herein, refers to "the positions", which has explicit antecedent basis.

Claims 1-28 were rejected under 35 U.S.C. § 103(a), as being unpatentable over U.S. Pat. No. 5,896,481 to Beranek, *et al.* This rejection was respectfully traversed for the following reasons.

Independent claim 1 concerns the installation of optical components on an optical bench to form an optical train. The positions of the optical components are then measured. This can be performed, for example, with modern metrology systems. The optical components are then aligned in response to the measurements.

This approach has advantages relative to the state-of-the-art, such as described in Beranek, *et al.* Patent. Specifically, in the past, active or passive alignment processes have been used to align the optical trains of fiber optic systems. The problem was active alignment was slow. An active element, such as a laser, had to be energized, and then the coupling between the laser and the end face of an optical fiber aligned to the active element, in response to the amount of light coupled into the fiber. This could yield very high coupling efficiencies, but was slow. The other approach, as also described in the Beranek, *et al.* Patent was passive alignment. Here, the optical system was designed so that the active element and the fiber would be aligned during the process of installation. The problem with this approach, however, was that it produced very poor coupling efficiencies and/or yields in most commercial production environments.

The present invention is directed toward a solution that can achieve the accuracy of active alignment, but with the ease of operation of passive alignment. Specifically, the positions of optical components in the optical train are measured. They then are aligned in response to the data from these measured positions. As a result, a generally passive technique can yield alignment accuracies approaching that achieved in active alignment.

The Beranek, *et al.* Patent neither shows nor suggests this combination of steps including measuring the positions of optical components and then aligning the optical

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components to the positions. As stated earlier, it seems to prefer a generally conventional passive alignment technique.

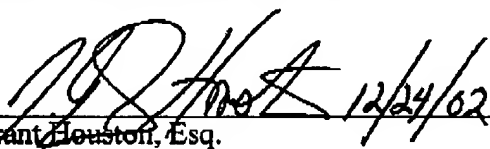
For the foregoing reasons, Applicants believe that the present claimed invention is distinguishable over the applied reference. Withdrawal of the rejection is respectfully requested.

Attached hereto is a marked-up version of the changes made to the specification and claims by the instant amendments. The attached appendix is captioned "Version with Markings to Show Changes Made." Please note that due to the amendments, the page and line numbers may be different from the specification as originally filed. Please further note that the page and line numbers hereinabove are relative to the original specification.

Applicants believe that the present application is in condition for allowance. A Notice of Allowance is respectfully solicited. Should any questions arise, the Examiner is encouraged to contact the undersigned.

Respectfully submitted,

AXSUN TECHNOLOGIES, INC.

By  12/24/02  
J. Grant Houston, Esq.  
Registration No.: 35,900  
Tel.: (978) 262-0049  
Fax: (978) 262-0035

Billerica, Massachusetts 01821  
Date: 6 October 2002

## APPLICATION FOR UTILITY PATENT

Date: 1/16/2001 Express Mail Label No. EL 742642512 US

Inventor(s): Steven D. Conover,  
7 Hillside Lane, Chelmsford, MA 01824 (U.S. citizen);  
Randal A. Murdza,  
55 Foxwood Drive, North Andover, MA 01845 (U.S. citizen);  
Margaret B. Stern  
177 Plympton Rd, Sudbury, MA 01776 (U.S. citizen).

Attorney's Docket No.: 1064US

## Optical Component Installation and Train Alignment Process Utilizing Metrology and Plastic Deformation

### BACKGROUND OF THE INVENTION

Component alignment is of critical importance in microoptical systems and especially semiconductor and/or MOEMS (microoptical electromechanical systems) optical system manufacturing. The basic nature of light requires that light generating, transmitting, and modifying components must be positioned accurately with respect to one another, especially in the context of free-space-interconnect optical systems, in order to function properly and effectively. Scales characteristic of optical semiconductor and MOEMS technologies can necessitate micron to sub-micron alignment accuracy.

Consider the specific example of coupling light from a semiconductor diode laser, such as a pump or transmitter laser, to single mode fiber. Only the power that is coupled into the fiber core is usable, and the coupling efficiency is highly dependent on accurate alignment between the laser output facet and the core; inaccurate alignment can result in partial or

complete loss of signal transmission through the optical system. Moreover, if polarization-maintaining fiber is used, there is an added need to rotationally align the fiber relative to the laser to maintain the single polarization characteristic of the output signal.

Other more general examples include optical amplification, receiving and/or processing systems. Some alignment is typically required between an optical signal source, such as the fiber endface, and a detector. In more complex systems including tunable filters, for example, alignment is required not only to preserve signal power, dynamic range, but also to yield high quality systems through the suppression of undesirable optical modes within and without the systems.

In the example of a tunable filter system, light, typically provided by fiber, is supplied to an optical train, including a tunable filter, such as a Fabry-Perot (FP) tunable filter. The launch characteristics of the light into the FP filter cavity determine the side mode suppression ratio (SMSR) of the system. This ratio, in part, dictates the quality of the system. If light is launched into the filter at the wrong position or with the wrong spot size, higher order modes are excited in the filter, degrading the system's SMSR. Typically, filter train alignment is employed to extract the highest possible SMSR.

Generally, there are two types of alignment strategies: active and passive. Typically, in passive alignment of the optical components, registration or alignment features are fabricated directly on the optical components, such as the optical elements or element mounting structures, as well as on the platform to which the components are to be mounted. The components are then mounted and bonded directly to the platform using the alignment features. In active alignment, an optical signal is transmitted through the components and detected. The alignment is performed based on the transmission characteristics to enable the highest possible performance level for the system.

In the context of commercial volume manufacturing, selection between active and passive alignment, or some mix of the two, is determined based on the quality of part needed. Lower cost, lower performance devices are typically manufactured with entirely passive

alignment strategies, whereas the manufacture of high performance devices typically involves at least some active alignment.

## SUMMARY OF THE INVENTION

In the manufacture of optical systems, it is typically possible to passively align two optical components, such as components including lenses. In micro-optical trains, where beam diameters are typically less than one millimeter and usually less than 500 micrometers, alignment accuracies of 10 micrometers are possible with commercially available bonding machines, such as flip-chip bonders or other techniques utilizing jigs or optical component templates.

Tolerance stack up problems, however, are encountered when constructing more complex optical trains. For example, when more than two lenses must be aligned with respect to each other and possibly a fiber endface, for example, alignment tolerances at the component level become more rigorous because of how the tolerances affect each other in the aggregate.

Moreover, in some optical systems, such as high quality carrier-class systems and/or systems that have tunable optical filters, alignment tolerances of better than 5 micrometers are common. And, in some implementations, sub micrometer alignment tolerances are required, and even sub-100 nanometer tolerances can be required to achieve high side mode suppression ratios, for example, in tunable filter systems or when maximizing coupling efficiency.

In such optical systems, the alignment tolerances are more rigorous than that which can be obtained with conventional passive alignment techniques, especially when constructing optical systems with higher levels of integration. As a result, active alignment can be required. Active alignment, however, can be a slow process, especially when the initial alignment of the optical train is poor.

The present invention is directed to a micro-optical train manufacturing process, in which the positions of optical components on an optical bench are characterized, typically

using metrology systems. These optical components are then aligned with respect to each other in a passive alignment step based on data from the metrology system and system design information. As a result, a subsequent active alignment process can be avoided in some situations, or if a subsequent active alignment process is performed, the time required for that active alignment process can be reduced because of this metrology-based passive alignment step.

In general, according to one aspect, the invention features a micro-optical train manufacturing process. This process comprises installing optical components onto an optical bench to form an optical train. The positions of the optical components are then determined or characterized. The optical components are then aligned in response to these determined positions.

The position information can be relative to a coordinate system defined by the bench, for example, or simply relative information that describes the position of the optical train components relative to each other.

In the preferred embodiment, preferably prior to the installation step of the optical components on the optical bench, the optical properties of at least some of the optical components are determined, such as focal length, in some embodiments. Further, the positions of optical elements of the optical components are preferably characterized, especially in implementations in which the optical components comprise optical elements, such as lenses or filters, which are attached to mounting structures. Specifically, the position of an optical element relative to a mounting structure for optical components is determined. In one example, light is transmitted through lens optical elements and the metrology system defocused to image on the light spot of the transmitted light. The mounting structure is then located within the optical train. The optical axis of the optical element is then known by reference to the position of the mounting structure and element offset information.

In the preferred embodiment, bonding processes are used that are compatible with carrier-class optical systems. For example, preferably solder bonding, using eutectic solders



for example, or thermocompression bonding, ball bumping, and/or ultrasonic wire bonding are used to attach the optical elements to the mounting structures and the component mounting structures in turn to the optical bench.

In the typical implementation, the optical elements are installed on the optical bench in a relatively fast, but relatively low precision, installation process. Specifically, the optical components are installed on the optical bench to a precision of less than one micrometer, such as within 10 micrometers of their optimal location. Typically, with solder bonding techniques, positions of the optical components can shift by approximately 4 micrometers, in some instances.

Metrology data, however, are collected, providing the location of the optical components on the bench and/or relative to each other.

Then a passive alignment process is preferably performed in which the optical components on the bench are aligned by reference to the metrology data and the desired optical element positions based on the system design. This provides a gross alignment of the optical train, which in some cases will be the only alignment that is required. In the current embodiment, this alignment is performed by plastically deforming mounting structures of the optical components.

Thereafter, an active alignment step is performed, in one implementation, in which an optical signal is transmitted through the optical train and the optical components are then further aligned based upon the transmission characteristics of this optical signal in the optical train. For example, in one implementation, the magnitude of the optical signal transmitted through the optical train is used as the metric for driving the active alignment of the components. In alternative embodiments, a side mode suppression ratio of the filter train, such as in the case of a filter train including a tunable filter, is used as the alignment metric. Again, this final active alignment is performed by plastically deforming the optical elements, in a current implementation.

The above and other features of the invention including various novel details of construction and combinations of parts, and other advantages, will now be more particularly described with reference to the accompanying drawings and pointed out in the claims. It will be understood that the particular method and device embodying the invention are shown by way of illustration and not as a limitation of the invention. The principles and features of this invention may be employed in various and numerous embodiments without departing from the scope of the invention.

## BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings, reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale; emphasis has instead been placed upon illustrating the principles of the invention. Of the drawings:

Fig. 1 is a schematic diagram illustrating a micro-optical train manufacturing process according to the present invention;

Fig. 2 is a perspective view showing the installation of a lens-type optical element on a mounting structure to form an optical component;

Fig. 3 is an exploded perspective view of a tunable filter optical component in which a tunable filter optical element is installed on a filter mounting structure;

Fig. 4A and 4B illustrate metrology data collection regarding the location of the optical element relative to the mounting structure of the optical component;

Fig. 5 is a top plan view of an optical bench on which the lens optical components and tunable filter optical components are installed;

Fig. 6 is a perspective view of an optical system including tunable filter and lens optical components on the optical bench; and

Fig. 7 is a process diagram summarizing the optical train alignment process of the present invention.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. 1 schematically illustrates a manufacturing process for a micro-optical train that utilizes the principles of the present invention.

First, the optical elements 110 and the mounting structures 112 are combined into the optical components 114 in an optical component assembly step 210, in the illustrated embodiment.

Fig. 2 shows one example of an assembled optical component 114. An optical element 110, such as a concave or convex lens, is installed onto mounting structure 112. In a current implementation, the lens is manufactured from silicon or gallium phosphide using a mass transport process, although the invention is applicable to other micro lens systems. The mounting structure 112 is manufactured from a metal or other plastically deformable substance. Presently, the mounting structures 112 are manufactured using the LIGA process. LIGA is a German acronym that stands for lithography, plating, and molding. Mounting structures manufactured using other microforming, micromanufacturing processes are also relevant, however.

Fig. 3 illustrates assembly of an exemplary tunable filter optical component. Specifically, a MOEMS optical membrane substrate 110A is combined with a concave reflecting lens 110C using an intervening spacer layer 110B. This assembled filter optical element 110 is then installed on a filter mounting structure 112.

In one implementation, the optical elements are bonded to the mounting structures using epoxy. Generally, solder or other metal based bonding is preferred and even required for carrier-class optical system manufacture, such as thermocompression bonding, ball bumping, thermosonic, and ultrasonic bonding.

Returning to Fig. 1, two techniques are illustrated for solder bonding the optical elements 110 to the mounting structures 112.

Specifically, in one component assembly process, a component jig 120 is used to pre-assemble the optical element 110 and the mounting structure 112. For example, this jig has slots for holding a lens substrate and a larger slot for receiving the mounting structure 112. A solder perform or some type of predeposited solder is inserted between the mounting structure  
5 and the lens.

After jig pre-assembly, the optical components are inserted into a solder reflow oven (SRO) to reflow the solder and bond the optical elements 110 to the mounting structures 112 to form the optical components 114.

Alternatively, a high precision placement and bonding system is used to install the  
10 optical elements 110 on the mounting structures 112. One example of such a bonding system is a flip-chip bonder. Specifically, a Karl Suss FC150 flip-chip bonder is applicable to these requirements.

In still other embodiments, the optical elements and optical components are monolithically fabricated using combinations of existing technologies, such as RIE etched  
15 frame with deformable plated metal structures.

Returning to Fig. 1, regardless of the specific component assembly process, the optical components 114 are the result of the optical component assembly step 210. In the preferred embodiment, these optical components are then provided to an optical component metrology system 220.

20 In the current embodiment, the optical component metrology step 215 produces optical component metrology data 310 that characterize the position of the optical components 110 on the mounting structures 112.

Referring to Fig. 2, in one example, optical component metrology data 310 are acquired characterizing the location of the optical axis (oa) of the optical component 110  
25 relative to an alignment mark(s) 116 of the mounting structure 112. Alternatively, incidental

alignment features of the mounting structure are used on other implementations, such as an edge 116-1 of the structure or a center point between two top edges, for example.

The following table illustrates an example of optical component metrology data 310. Specifically, the x and y axis positions of the mounting structure (MS) are determined in a coordinate system of the metrology system. The optical axis (oa) of the lens optical element is also determined. From this information, the X offset information from the lens relative to the mounting structure is calculated. Similarly, the distance between the optical axis (oa) and the top of the mounting structure is calculated.

310:

	Lens 1	
	T1	T2
MS X Position	0.00326	0.003932
MS Y Position	0.78388	0.779252
oa X Position	-0.002978	-0.002445
oa Y Position	0.515247	0.51117
X Offset lens	-0.005628	-0.005638
X Offset centroid	0.00573	0.005891
Lens to MS top Y	0.268633	0.268082
Factor	1	
ave X Offset lens	0.0056	
ave Lens to MS top Y	0.2684	

Fig. 4A is an image of an optical component from metrology system 220. Specifically, light is transmitted through the optical element and the optical system of metrology system defocused and so that the optical element's optical axis is apparent based on the focal point of the light that is transmitted through the lens. This allows the metrology system to determine the location of the figure of merit of the optical element.

Fig. 4B shows the location of the mounting structure by the metrology system 220. Specifically, the mounting structure is located by reference to alignment features of the mounting structure--in this case a midpoint 410 between edges 116-1, 116-2. Also shown are the x-axis position 414 and y-axis position 412 of the optical axis oa of the optical component of mounting structure 112. This process yields the component metrology data 310, which characterize the relationship between the position of the optical axis oa of the optical element 110, for example, and alignment marks or features of the mounting structure 112.

Referring back to Fig. 1, the characterized optical components 114, along with optical benches 130, are supplied to an optical bench assembly process 230.

In this bench assembly process 230, the optical components 114 are installed on the optical benches 130.

Presently, one of two assembly modalities is used. In one example, a bench jig 1440 is used to locate the optical components 114 on the optical bench 130. These assembled benches are then placed in a solder reflow oven 122 to reflow solder between the optical components and the benches to permanently affix the optical components 114 to the benches 130.

In an alternative implementation, the precision placement and bonding machine 124 is again used to place and then solder bond the optical components 114 on the optical benches 130. Typically, machine vision systems are used by the placement and bonding system 124 to precision place the optical components on the benches 130 by reference to alignment features or marks on the benches.

In still other implementations, bonding systems utilizing epoxy bonding are used.

Fig. 5 illustrates an example of a non-populated optical bench 130. For example, this bench has metalizations, such as gold and/or predeposited solder areas 100 and bench alignment marks or features 22 that are used by the vision system of the placement and bonding system 124 to locate the optical components 114 relative to the bench 130. In other

implementations, physical registration features such as trenches, or raised registration blocks are formed on the surface of the bench 130.

Fig. 6 shows an exemplary populated bench that results from the bench assembly step 230 of Fig. 1. In this example, optical components including optical fiber components 114-1, including optical fiber ~~fF~~ and an associated mounting structure, lens components 114-2, including lens optical elements 54 and lens mounting structures, tunable filter optical components 114-3, detectors 114-5, active laser components 114-8, and passive filters 114-6 are installed to form the populated bench 131.

Typically, however, even with high precision placement in bench jigs 144 and stability during the SRO run 122 or well-calibrated placement and bonding machines 124, the optical components 114 are typically only installed on the optical bench 132 to placement accuracies of about 4 micrometers, or worse. Further, even in highly automated manufacturing processes, it is difficult to repetitively install the optical components on the optical bench to accuracies of better than 1 micrometer.

Returning to Fig. 1, a bench metrology step 240 is performed using a metrology system 220. Typically, the locations of the optical components 114, and specifically the mounting structures, relative to the bench 130 are measured. This yields bench metrology ~~130~~ data 330 that characterize the positions of the optical components relative to alignment features of the optical bench.

In the current embodiment, the metrology system 240 references the alignment features of the mounting structures of the optical components. Typically such metrology systems 240 includes precision bearing staging with microstepper motor control and 0.4 micrometer resolution linear encoder scales in X, Y, and Z axes. An integrated CCD camera acquires high-resolution images for the video image processing system and offers real time display, with geometric dimensioning and tolerancing.

The following table illustrates an example of bench metrology data 330. Specifically, the x and y axis positions of a fiber mounting structure (MS), along with a lens mounting

structure are determined in a coordinate system of the bench. Data column T1 represents data acquired by the metrology system 240, including component angle data. The target column is the desired position as dictated by the optical system design. Column Dtarget represents the difference between the target data and measured data. The final lens adj column includes data

310.

330:

bench metalization define coordinate system		target	T1	D target	lens adj
fiber MS	Angle	0	0.158816	0.162	
P3	X	0.817	0.801167	(0.016)	
P3	Y	0	-0.003306	(0.003)	
P3Z	Z	0.88	0.888752	0.009	
Lens MS	Angle	90	90.072345	0.072	
P4	X	1.828	1.82541	(0.003)	
P4	Y	0	-0.006581	(0.006)	0.006
P4Z	Z	0.84	0.8514	0.012	(0.268)

This bench metrology data 330 and populated benches 131 are then passed to an alignment system 140 for a passive alignment step 250 based on the metrology data. In the preferred embodiment, this passive alignment is performed by the alignment system by plastically deforming the mounting structures 112 of the optical components 114. The alignment system 140 performs the passive alignment step 250 based upon the bench metrology data 330 and also preferably the optical component metrology data 310. By combining these two data sets, the optical axis of the individual optical elements of the optical train is aligned with respect to each other to almost the accuracy of the metrology system's data.

The passive alignment step 250 yields passively aligned benches 132. These are passed to a preferably similar or even the same alignment system 140 for an active alignment step 260. Specifically, an optical generation system 160 either injects an optical signal into



the optical train by a fiber optic link or energizes an active component within the optical system to generate an optical signal and thereby activate the optical train of the optical system of the bench. Simultaneously, an optical detection system 162 detects the optical signal after transmission through at least part of the optical train of the optical system. In one  
5 implementation, the optical detection system simply measures a magnitude of the optical signal that it detects. In an alternative embodiment, a spectral analysis of the optical signal can be performed to determine the side mode suppression ratio of the optical system. This is typically most easily accomplished by tuning a tunable filter within the optical train over a single frequency signal such as from a DFB laser. In some implementations, a detector is  
10 manually inserted into the optical train by the alignment system 140. Alternatively, an optical signal detector of the optical signal train is monitored to detect the magnitude of the optical signal that it receives.

In either case, the signal from the optical detection system 160 is used as a control signal to the alignment system 140. Specifically, the alignment system 140 plastically  
15 deforms the mounting structures 112 of the optical components 114 to improve the alignment of the optical components in the active alignment process 260.

Fig. 7 is a process diagram summarizing the manufacturing process of the present invention. Specifically, in an optical component characterization step 220, the locations of the optical axes of optical elements are determined relative to the optical components, and  
20 specifically the mounting structures in the illustrated implementation. This is most important when the optical elements 110 have been installed on mounting structures 112 and placement accuracy on those elements is a variable in determining the ultimate alignment of the optical train. This generates the optical component metrology data 310.

In a bench assembly step 230, the optical components 114 are installed on optical  
25 benches 130.

In the bench metrology step 240, the location of these optical components 114 on the optical benches 130 is characterized. Typically, in one implementation, the position of the

reference features of the optical components 114 are measured relative to reference marks on the optical benches 130. This yields bench metrology data 330 and characterized populated benches 131. This information is used by an alignment system 140 in combination with the component metrology data 310 in a preferred embodiment in passive alignment step 250.

5 Specifically, the optical components are aligned relative to each other on the optical bench using plastic deformation in one implementation.

Finally, in active alignment process 260, an optical signal is transmitted through the optical train and then detected. The characteristics of this detected signal is then used by an alignment system to actively align the optical system.

10 While this invention has been particularly shown and described with references to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the scope of the invention encompassed by the appended claims.

15

## CLAIMS

What is claimed is:

1. (amended) A micro optical train manufacturing process, comprising:  
installing optical components onto an optical bench to form an optical train;  
5 measuring positions of the optical components of the optical train; and  
aligning the optical components of the optical train in response to the determined  
positions.
2. A process as claimed in claim 1, wherein the step of installing the optical  
components comprises solder bonding the optical components to the optical bench.
- 10 3. A process as claimed in claim 1, wherein the step of installing the optical  
components comprises eutectic solder bonding the optical components to the optical  
bench.
4. A process as claimed in claim 1, wherein the step of installing the optical  
components is performed by a precision placement and bonding machine.
- 15 5. A process as claimed in claim 1, wherein the step of installing the optical  
components is performed in a solder reflow oven.
6. A process as claimed in claim 1, further comprising characterizing an optical  
property of at least some of the optical components prior to installing the optical  
components on the optical bench.
- 20 7. (amended) A process as claimed in claim 6, wherein the step of aligning the optical  
components of the optical train is further performed in response to the determined  
optical property.

8. A process as claimed in claim 1, further comprising determining focal lengths of at least one of the optical components prior to installing the optical component on the optical bench.

9. A process as claimed in claim 1, further comprising assembling optical components prior to attaching the optical components on the optical bench.

10. A process as claimed in claim 9, wherein the step of assembling the optical components comprises solder bonding optical elements to mounting structures.

11. A process as claimed in claim 9, wherein the step of assembling the optical components comprises thermally bonding optical elements to mounting structures.

12. A process as claimed in claim 1, wherein the optical components are installed on the optical bench to a precision of less than 4 micrometers.

13. A process as claimed in claim 1, wherein the optical components are installed on the optical bench to a precision of less than 1 micrometer.

14. A process as claimed in claim 1, wherein the step of determining the positions of the optical components comprises determining positions of the optical components relative to reference marks on the optical bench.

15. A process as claimed in claim 1, wherein the step of determining the positions of the optical components comprises determining distances between the optical components.

16. A process as claimed in claim 1, wherein the step of determining the positions of the optical components is performed by a vision system by reference to predetermined features of the optical components.

17. A process as claimed in claim 1, wherein the step of determining the positions of the optical components comprises determining positions of optical elements of the optical components.

18. A process as claimed in claim 1, wherein the step of determining the positions of the optical components comprises determining positions of mounting structures of the optical components.

19. A process as claimed in claim 1, wherein the step of aligning the optical components comprises passively aligning the optical train.

20. A process as claimed in claim 1, wherein the step of aligning the optical components comprises plastically deforming the optical components.

21. (amended) A process as claimed in claim 1, further comprising, after aligning the optical components in response to the determined positions, actively aligning the optical components of the optical train.

22. A process as claimed in claim 21, wherein the step of actively aligning the optical components comprises deforming the optical components.

23. (amended) A process as claimed in claim 1, further comprising, after aligning the optical components in response to the determined positions, transmitting an optical signal through the optical train and further aligning the optical components of the optical train in response to the transmission of the optical signal through the optical train.

24. (amended) A process as claimed in claim 23, wherein the step of aligning the optical components in response to the optical signal comprises deforming the optical components.

25. (amended) A process as claimed in claim 23, wherein the step of aligning the optical components in response to the optical signal comprises deforming mounting structures of the optical components.

5 26. (amended) A process as claimed in claim 23, wherein the step of aligning the optical components in response to the optical signal comprises aligning the optical components to maximize a level of the optical signal that is transmitted through the optical train.

10 27. (amended) A process as claimed in claim 23, wherein the step of aligning the optical components in response to the optical signal comprises aligning the optical components to maximize a side mode suppression ratio of a tunable optical filter in the optical train.

15 28. A process as claimed in claim 1, further comprising characterizing a position of an optical element on mounting structure of the optical components prior to installing the optical components on the optical bench by reference to light that is transmitted through the optical element.

## ABSTRACT OF THE DISCLOSURE

### Optical Component Installation and Train Alignment Process Utilizing Metrology and Plastic Deformation

A micro-optical train manufacturing process includes a step of characterizing the position of optical components on an optical bench, typically using a metrology system. These optical components are then aligned with respect to each other in a passive alignment step based on data from the metrology system and optical system design information. As a result, a subsequent active alignment process can be avoided in some situations, or if a subsequent active alignment process is performed, the time required for that active alignment process can be reduced because of this initial metrology-based passive alignment step.